

Designing scenes to quantify the performance of automotive perception systems

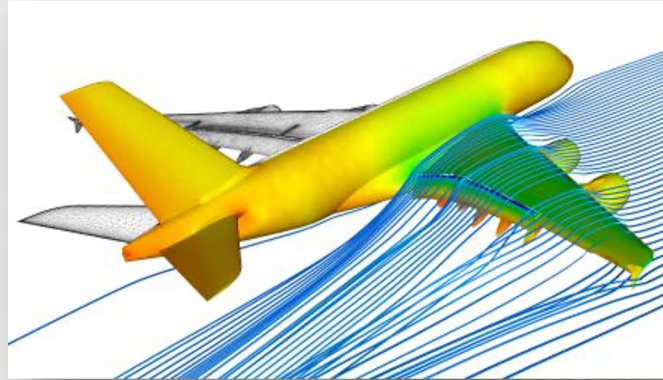
Zhenyi Liu*, Devesh Shah**, Alireza Rahimpour**, Joyce Farrell* and Brian Wandell*.
*Stanford University**, *Ford Motor***



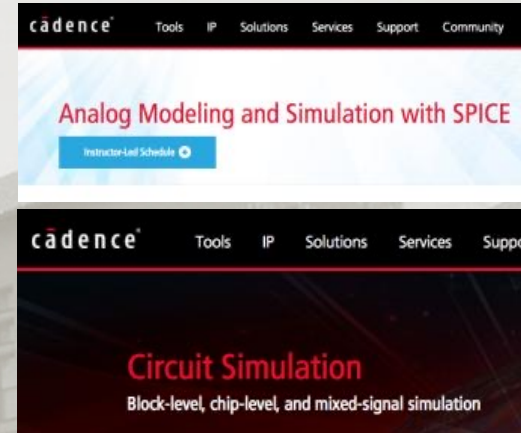
Systems simulation is important in many mature industries



ECU (Electronic Control Unit) Simulation for Automobiles



Numerical flow simulation on an Airbus A380



Integrated circuitry

Image systems engineering can benefit from simulation

- Simulators exist for components (scenes, optics, sensors)
- Measuring system performance using **quantified** (units) inputs is important

Scenes

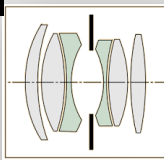
Ray traced spectral scene simulations



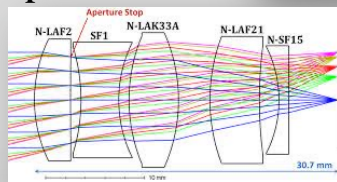
Optics



Spherics

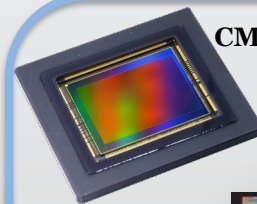


Aspherics

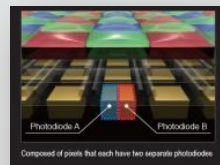


Sensors

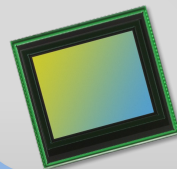
CMOS Bayer



Microlens



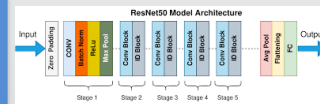
Dual or multipixel autofocus



RCCC automotive

Processing ³

Deep networks



PyTorch



Designing scenes to quantify the performance of automotive perception systems

- Image systems simulation (7 min)
 - **Soft prototyping**
 - **Synthetic data**
- Simulation and **image quality** (11 min)
 - Metric scene collections (**MSC**)
 - MTF (SFR) as a metric
 - Image quality performance (**IQP**) maps

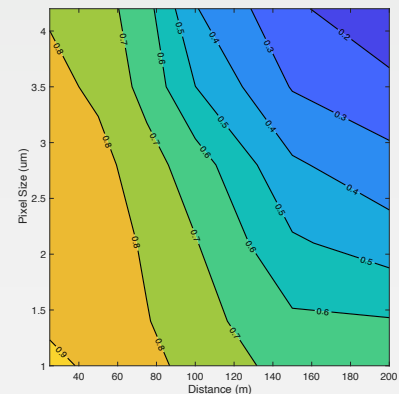


Image systems simulation status: 3D image systems simulation overview

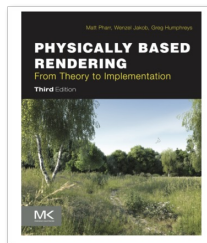
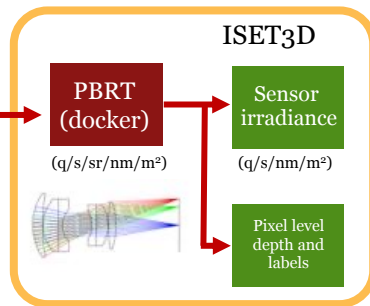
Asset generation



Scene Auto-assembly

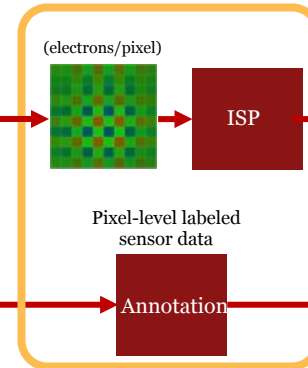
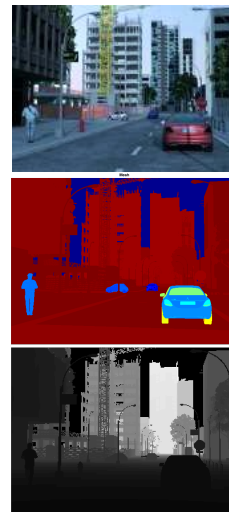


Sensor spectral irradiance



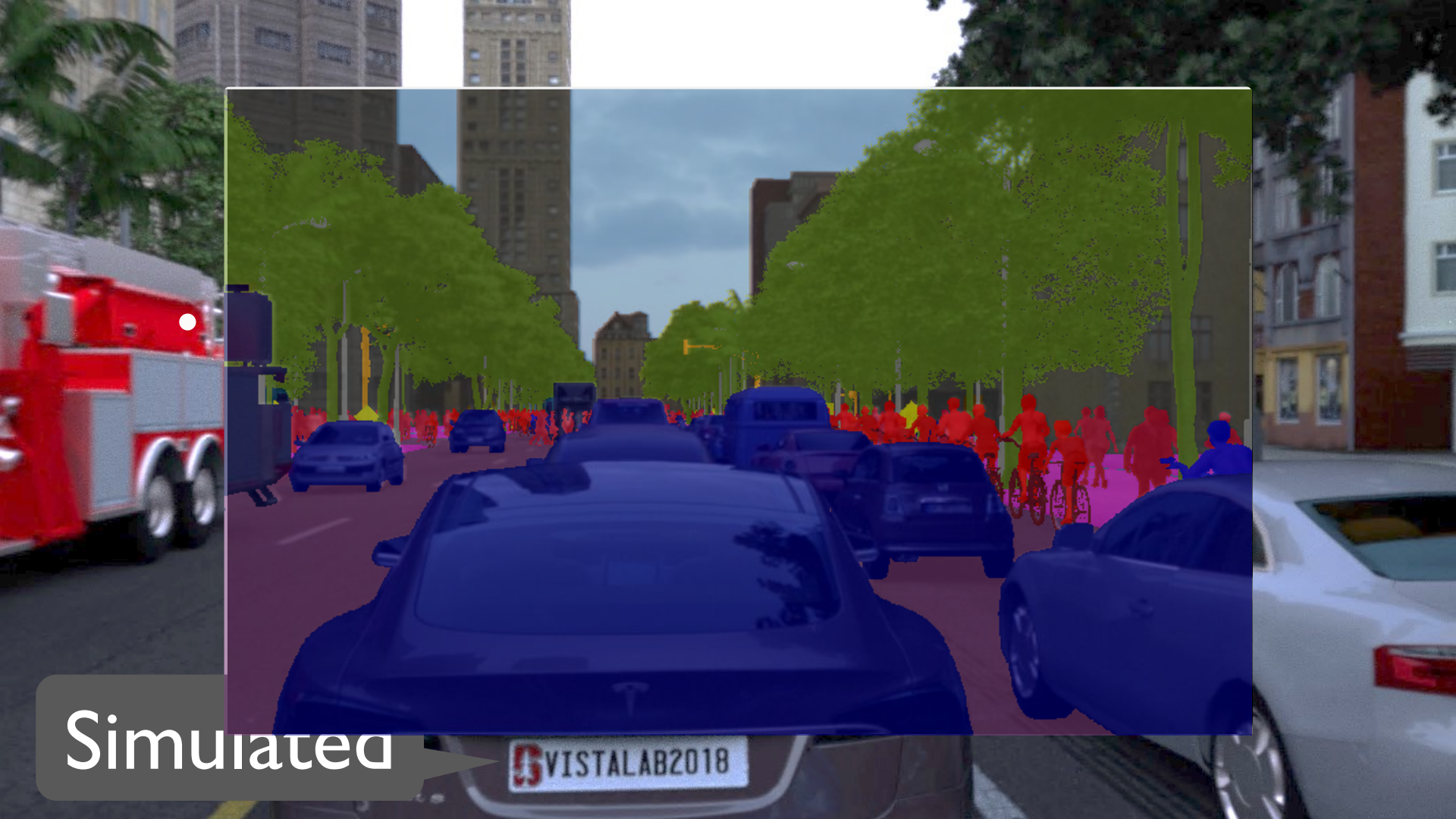
Sensor modeling

ISETCam



Training





Simulated

VISTALAB2018

Recent emphasis: Simulations of nighttime and rural roads



Night



Day



Fog Simulation

Validation of Physics-Based Image Systems Simulation With 3-D Scenes

Zheng Lyu¹, Thomas Goossens, Brian A. Wandell², and Joyce Farrell³

- ✓ Surface inter-reflections
- ✓ Depth of focus
- ✓ Vignetting
- ✓ Sensor quantum efficiency
- ✓ Sensor noise



Neural Network Generalization: The Impact of Camera Parameters

ZHENYI LIU^{1,2}, TRISHA LIAN², JOYCE FARRELL², AND BRIAN A. WANDELL²

¹State Key Laboratory of Automotive Simulation and Control, Jilin University, Changchun 13000, China

²Department of Electrical Engineering, Stanford University, Stanford, CA 94305, USA

Corresponding author: Zhenyi Liu (zhenyiliu27@gmail.com)

This work was supported by the Jilin University.

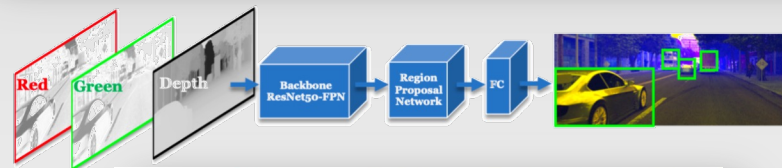
ISETAuto: Detecting vehicles with depth and radiance information

ZHENYI LIU¹, JOYCE FARRELL² AND BRIAN WANDELL²

¹State Key Laboratory of Automotive Simulation and Control, Jilin University (e-mail: zhenyiliu27@gmail.com)

²Stanford University (e-mail: jefarrel, wandell@stanford.edu)

Corresponding author: Zhenyi Liu (e-mail: zhenyiliu27@gmail.com)



Train \ Eval	KITTI (real) (11671 cars)	BDD (real) (31384 cars)	CITYSCAPE (real) (25368 cars)	ISETAuto* (synth) (30813 cars)
KITTI	0.895	0.6749	0.6469	0.6173
BDD	0.2543	0.6946	0.4228	0.4734
CITYSCAPE	0.3526	0.6613	0.6960	0.5857
ISETAuto	0.2543	0.5978	0.4817	0.7992

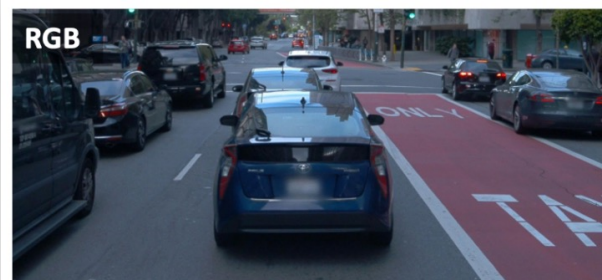


Image quality is an active topic in automotive applications

- Lab calibration methods
 - ISO 16505 (multiple)
 - ISO 18844 (flare)
- Real world testing

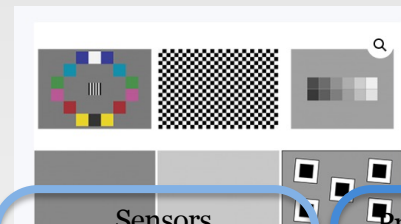
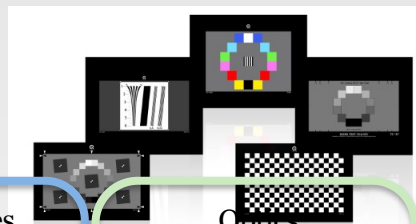
IEEE P2020
IEEE Draft Standard for Automotive System Image Quality
STANDARD by IEEE,
[View all product details](#)

Priced From (in USD)

\$180.00
Members pay \$144.00

Image Engineering

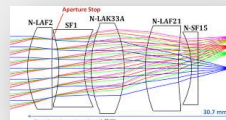
Imatest



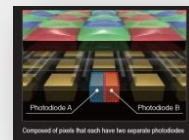
Scenes



Optics



Sensors



Processing



Image systems simulation: Relating image quality to object detection

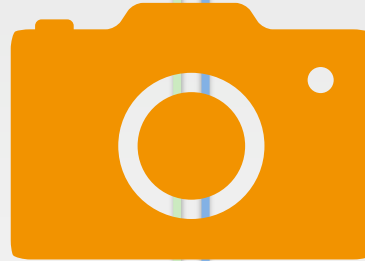
Metric scene
collections (MSC)



Standards - test charts

Optics

Use vendor information for optics,
sensor, acquisition policies

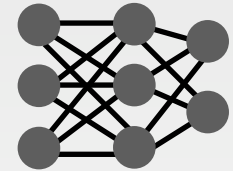


Intellectual property issues

Sensors

Processing

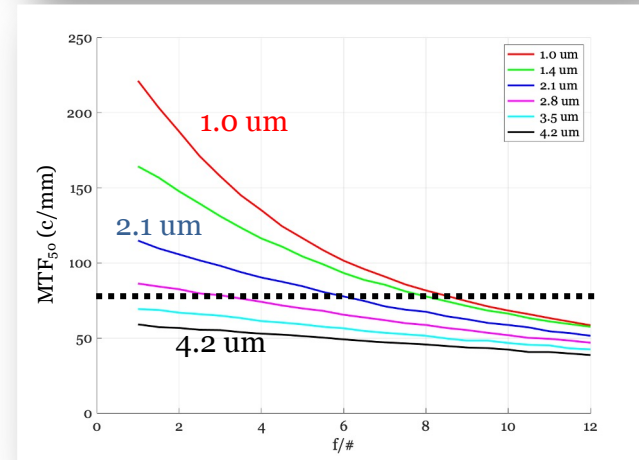
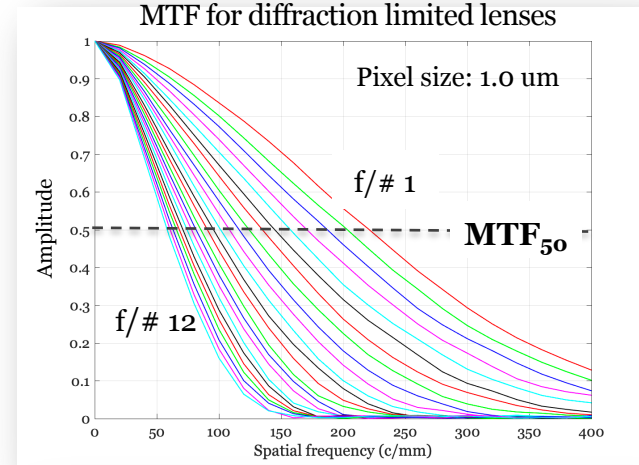
Specify
processing



Simply software

How well does the MTF predict object detection performance?*

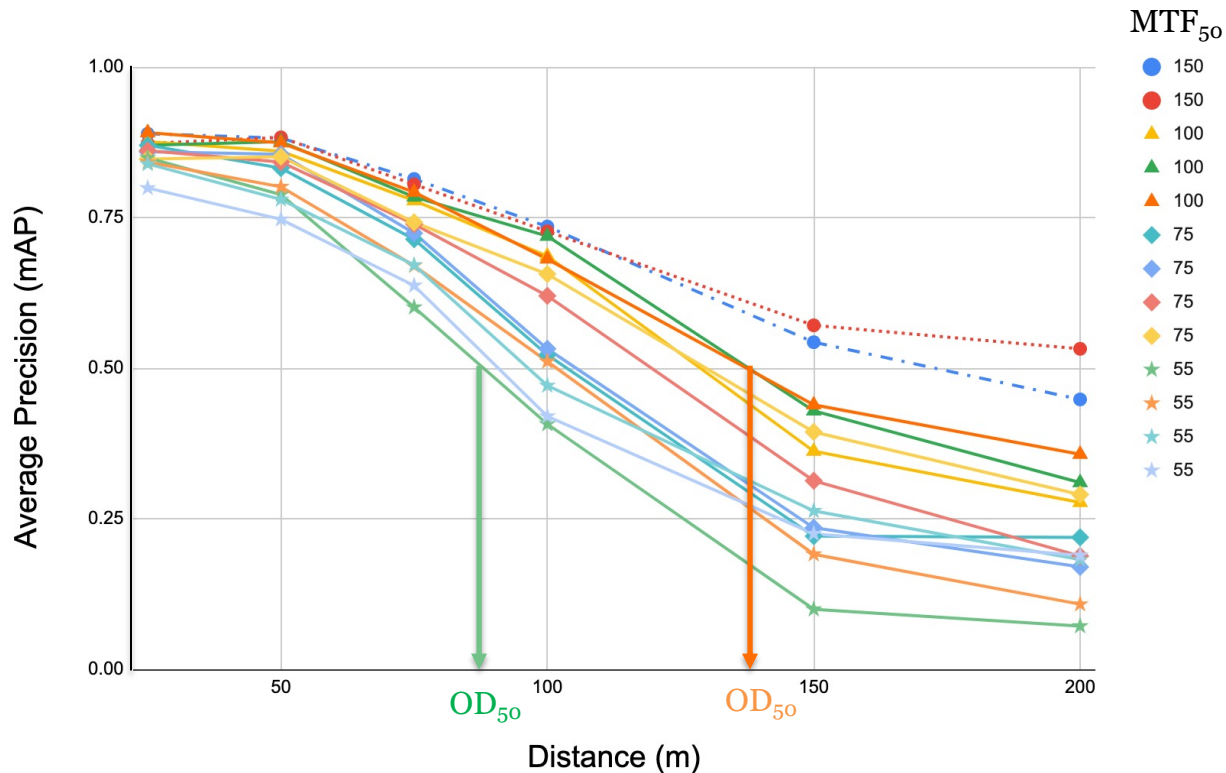
- The modulation transfer function (MTF*) is commonly used to characterize optics and other linear systems
- The image system MTF depends on the optics (f/#) and pixel size
- The MTF_{50} is the spatial frequency at which the contrast reduction is 50%
- Many combinations of pixel size and f/# have the same MTF_{50} value
- **Do systems with the same MTF_{50} have the same object detection performance?**



* In this community, MTF is also called Spatial Frequency Reduction (SFR)

Do systems with the same MTF_{50} produce similar object detection performance?

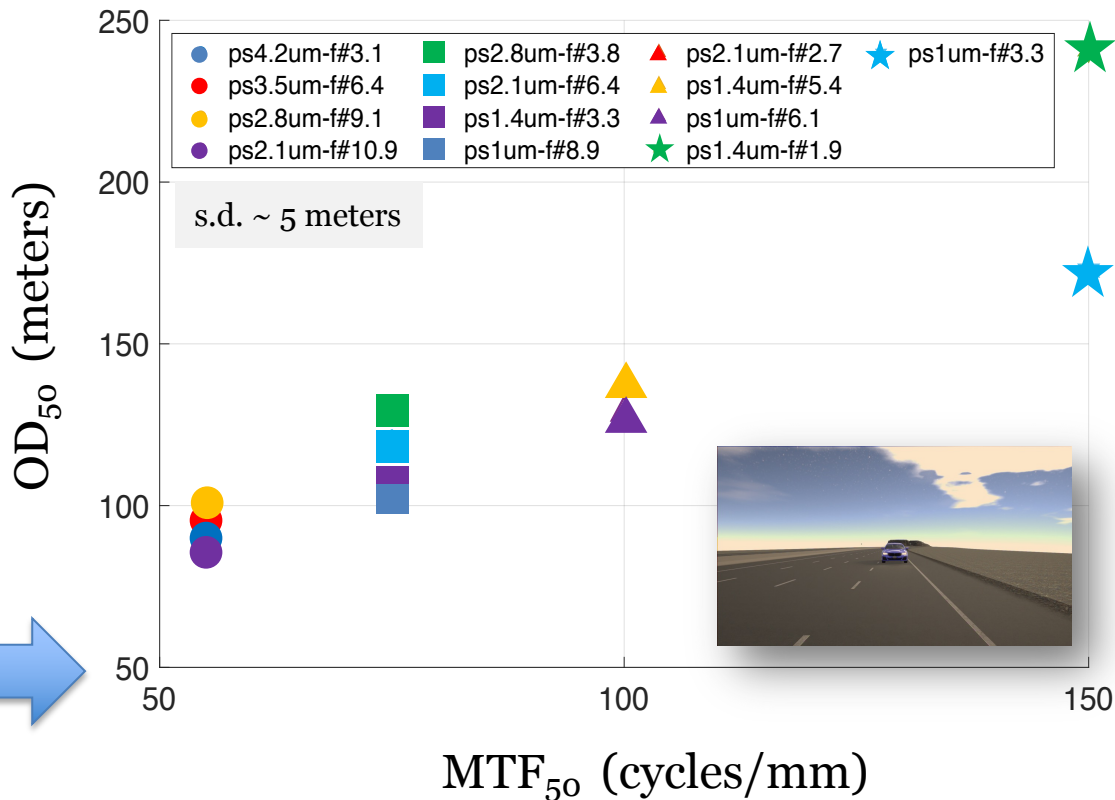
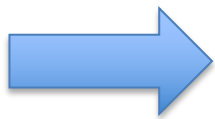
- We estimated object detection as a function of distance using mean average precision
- We calculated the full curve for each of the simulated cameras
- We summarize object detection performance using the OD_{50}



MTF₅₀ explains a lot of OD₅₀ variance, but not all - Daytime

- Simulating daytime conditions, we find the MTF₅₀ is largely predictive of the OD₅₀
- But there is unexplained variation

*See contribution by Patrick Muller and Alexander Braun at this meeting for a similar conclusion



MTF₅₀ explains a lot of OD₅₀ variance, but not all - Nighttime

- Under nighttime conditions, the MTF₅₀ is also predictive of the OD₅₀
- But the absolute object detection performance level is very different between Day and Night
- Thus, the MTF is a valuable predictor of performance for a specific condition

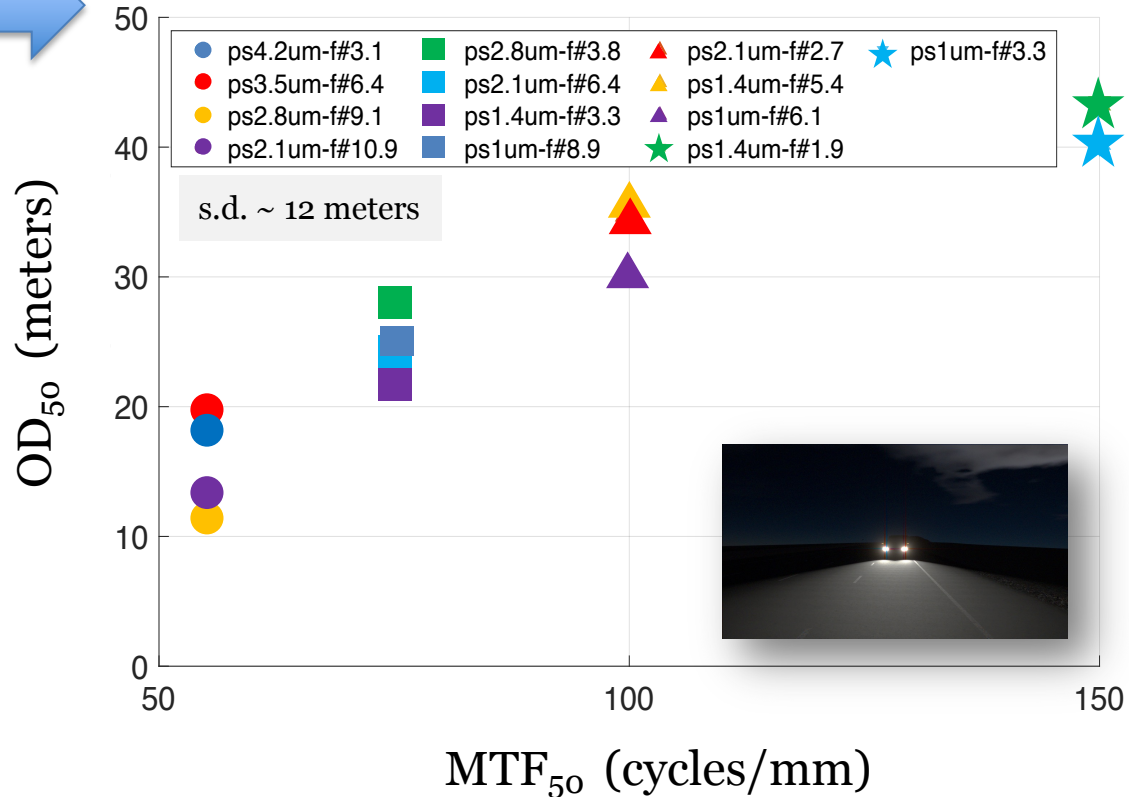
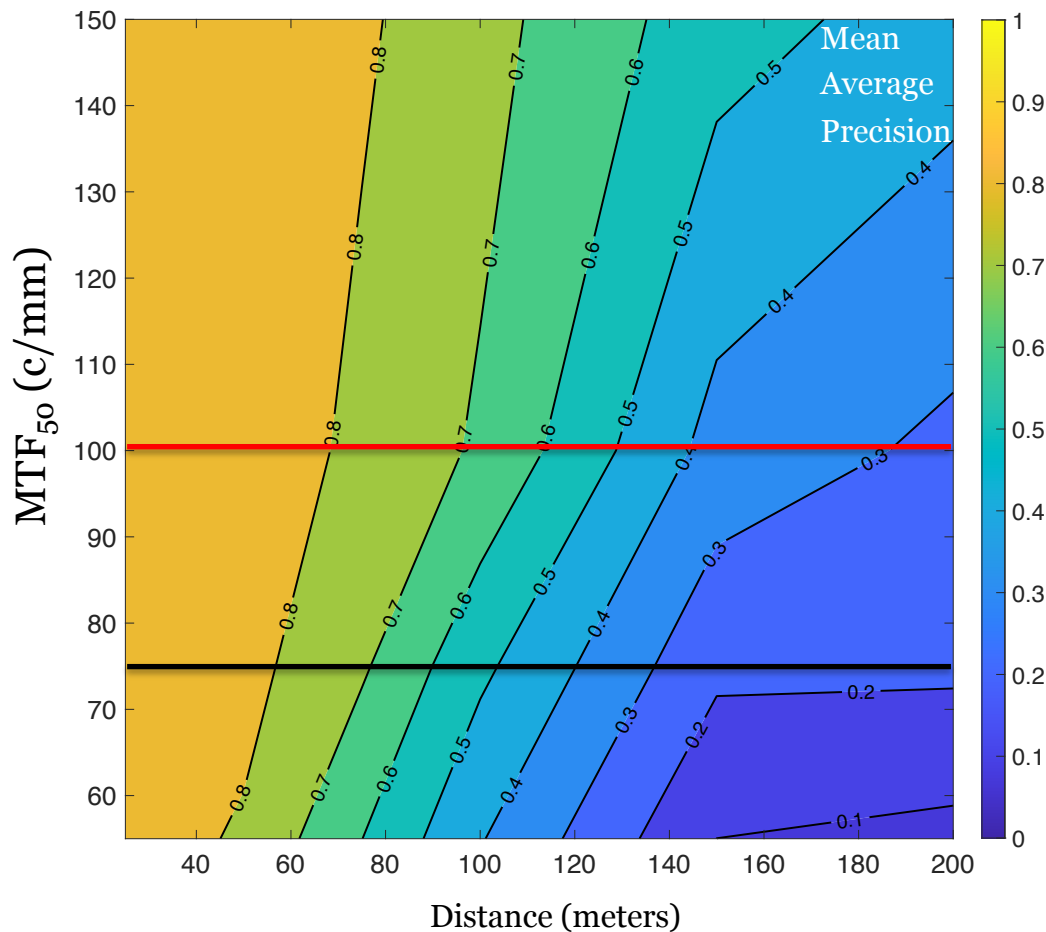
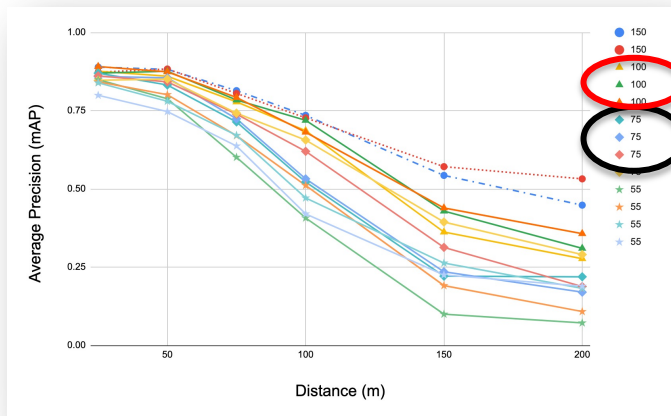


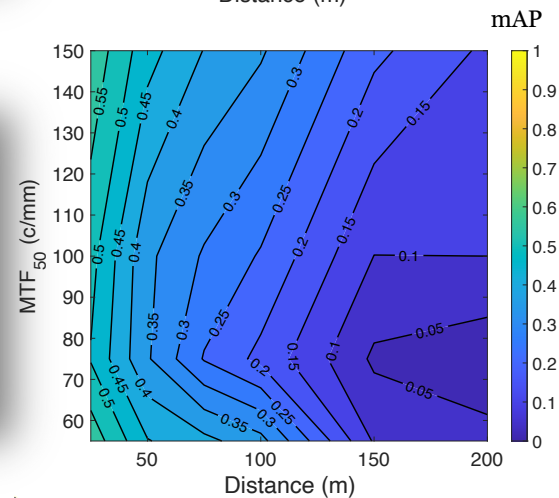
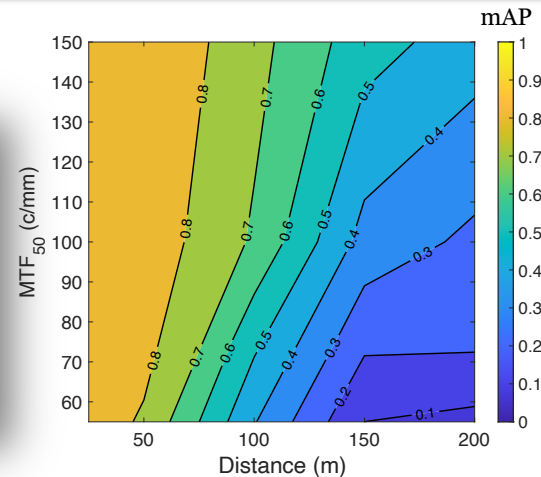
Image quality performance (IQP) maps

- The average precision data for object detection for pairs of variables can be represented as an image quality and performance (IQP) map
- The MTF_{50} value determines the row; the distance to the car determines the column
- The color and contour lines show the mean average precision (mAP)



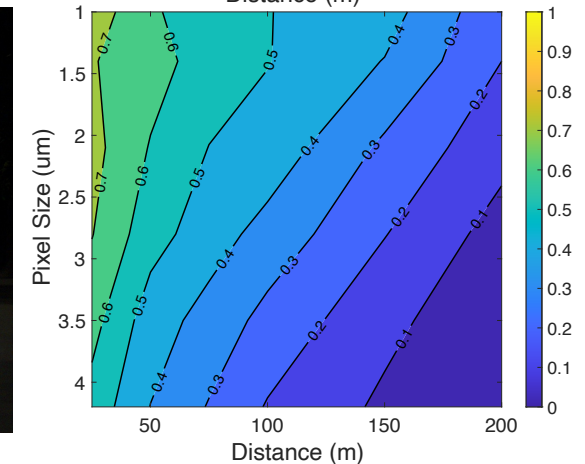
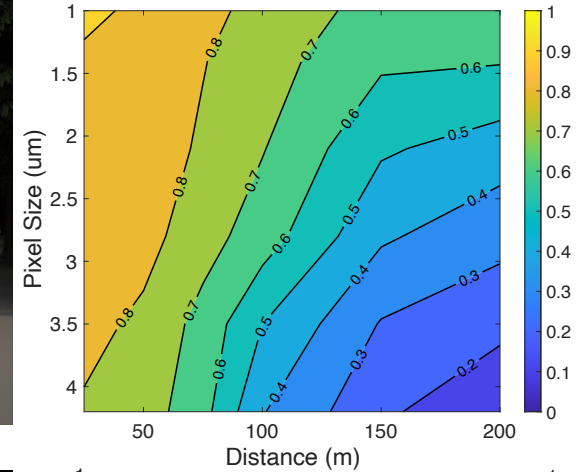
MTF₅₀ relationship to OD₅₀ depends strongly on day vs. night

- The image quality performance (IQP) map simplifies comparisons between conditions
- These IQP maps represent object detection performance as a function of distance and MTF₅₀
- One map shows daytime and the other nighttime

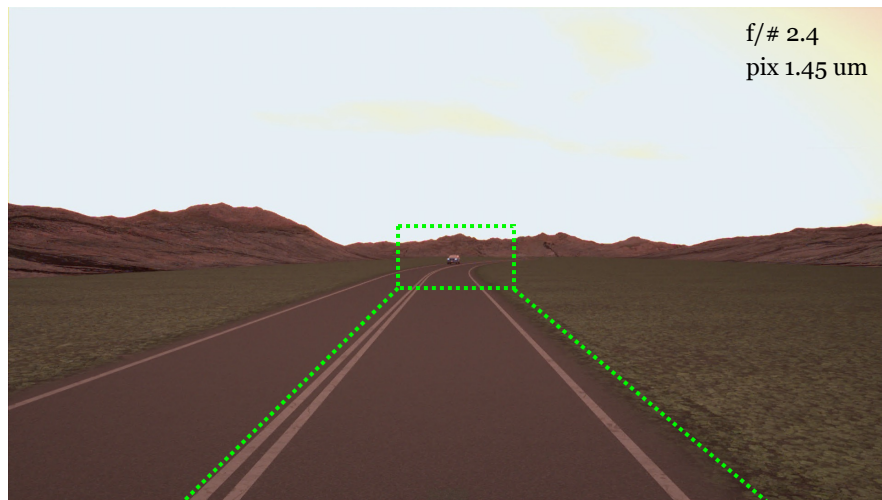
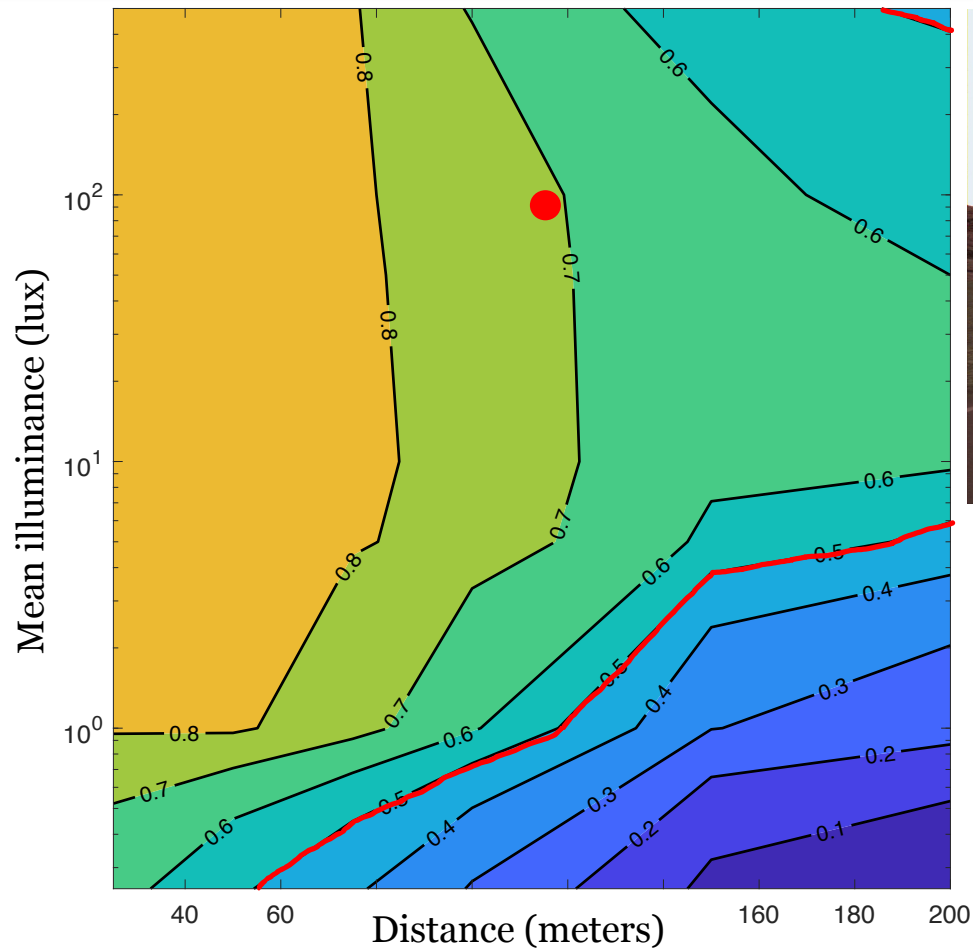


Pixel Size vs Distance

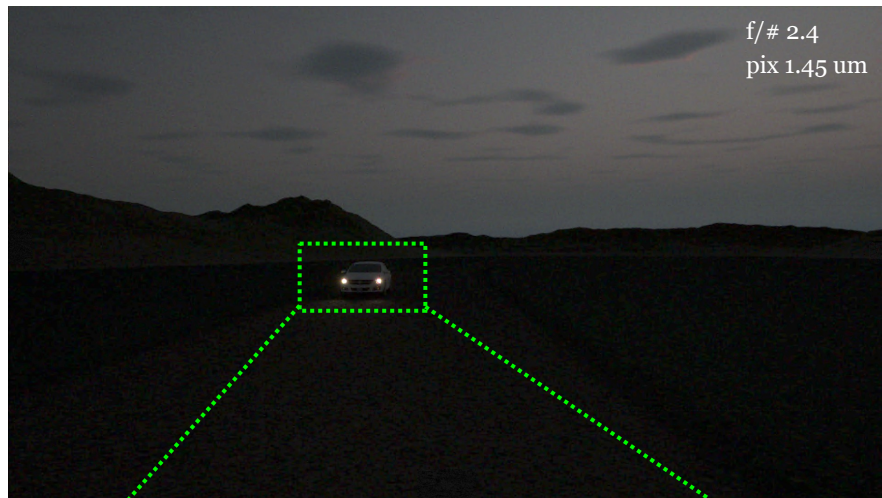
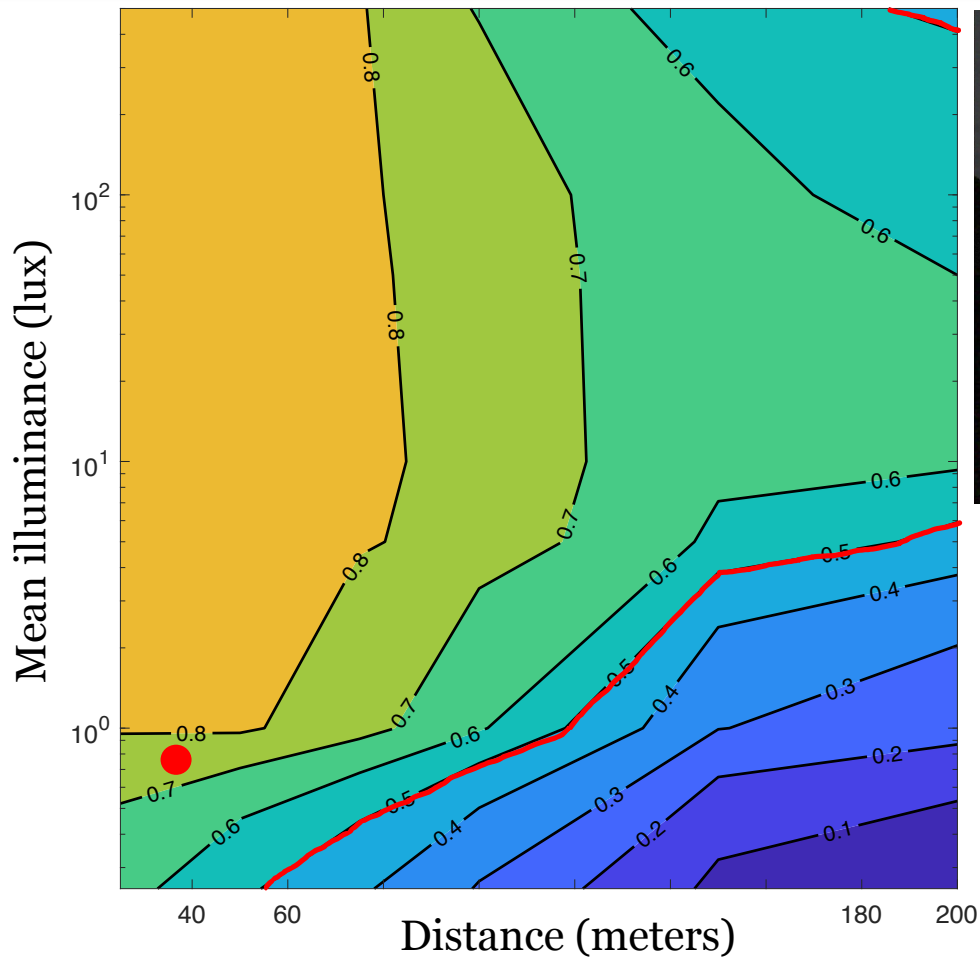
- The IQP maps compare object detection distance and pixel size for a fixed diffraction limited lens (f/#2.4)
- The pixel sizes range from 1-4.2 microns
- Again, we separate the daytime and nighttime conditions



Using the IQP maps to select scenes and understand performance

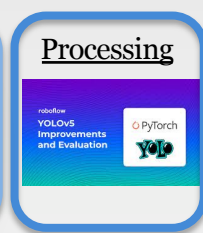
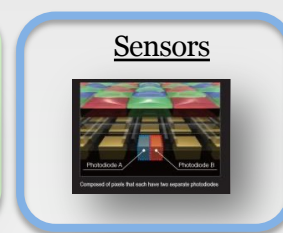
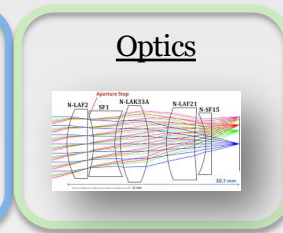
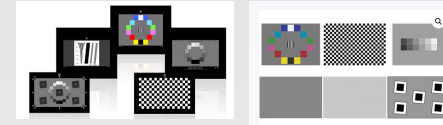


Using the IQP maps to select scenes and understand performance



Conclusions

- We describe using image systems simulation to measure the impact of image quality on performance (IQP maps)
- System simulation fits between lab testing and field testing, offering an assessment that's closer to the system's design objective
- Consensus on key performance indicators can speed progress in evaluation and support purchasing decisions



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